Using Support Vector Machine (SVM) along with GPS ionospheric TEC estimations for potentially predicting earthquake events

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Talk outline:

- Main motivation and background
- Data sources
- Methodology
- Results
- Conclusions

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Main motivation:

New insights regarding the controversy concerning precursors which may precede earthquakes

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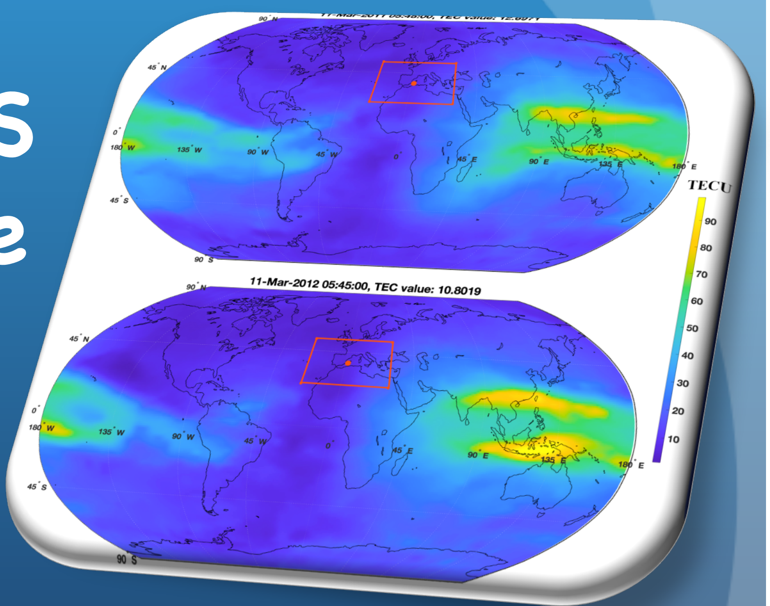
Main motivation:

Implementing ML Support Vector Machine (SVM) technique, applied with GPS ionospheric TEC, to evaluate potential earthquake precursors manifested as disturbances in the ionospheric TEC data.



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Background:

Over the last three decades, numerous studies have presented promising results related to natural hazards mitigation, particularly for earthquake precursors, while other studies have refuted them.

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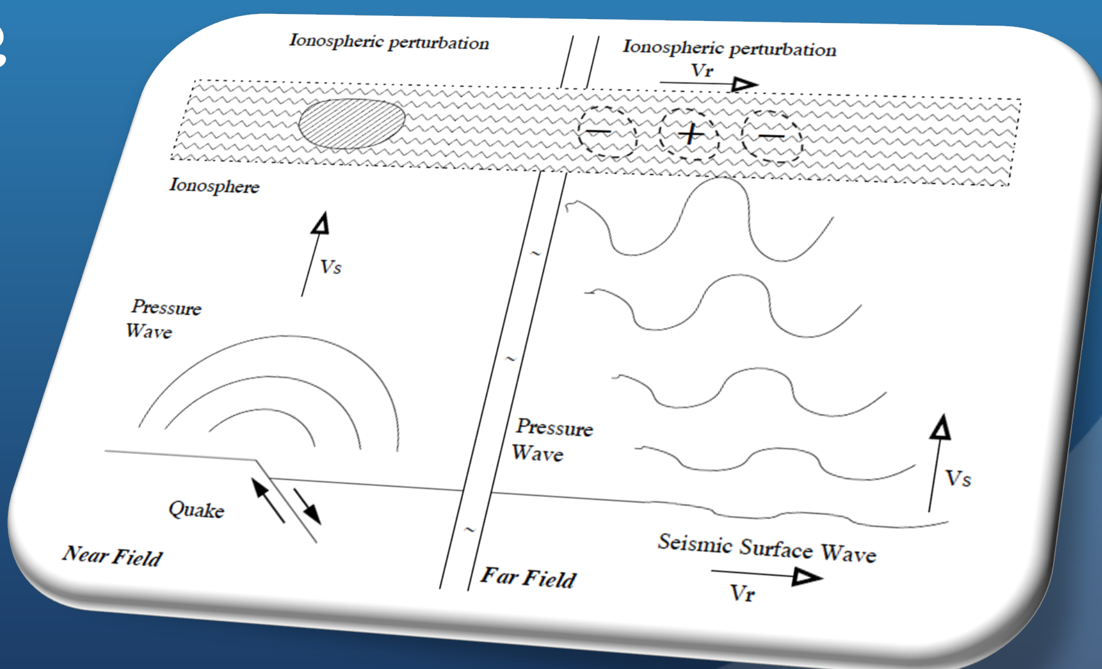
Background:

Natural hazard signatures associated with strong earthquakes appear not only in the lithosphere but also in the troposphere and ionosphere



Background:

Current observational and modeling results have confirmed the existence and detectability of earthquake and tsunami signatures in the ionosphere caused by both acoustic and gravity waves, disturbing the electron density in the F-region [Heki and Ping, 2005; Heki et al., 2006; Astafyeva et al., 2009; Stangl et al., 2011]:

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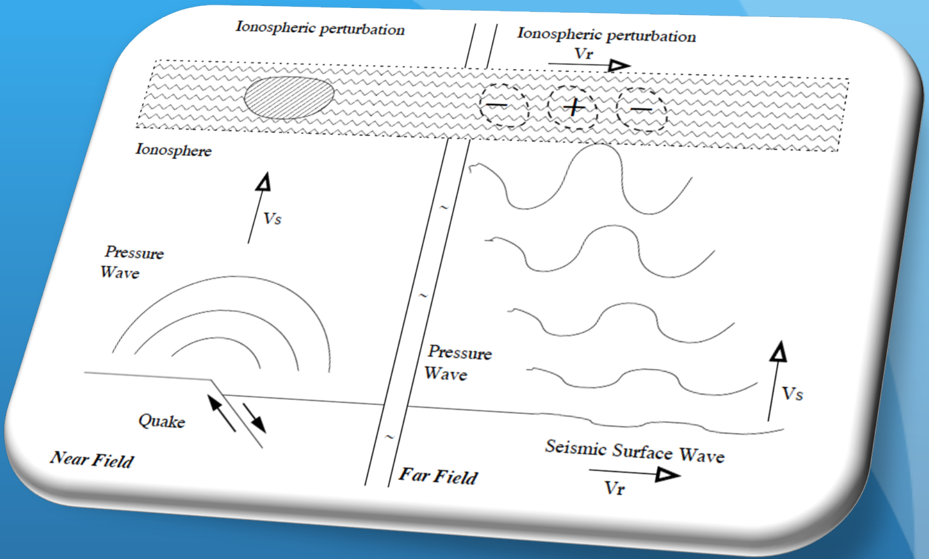
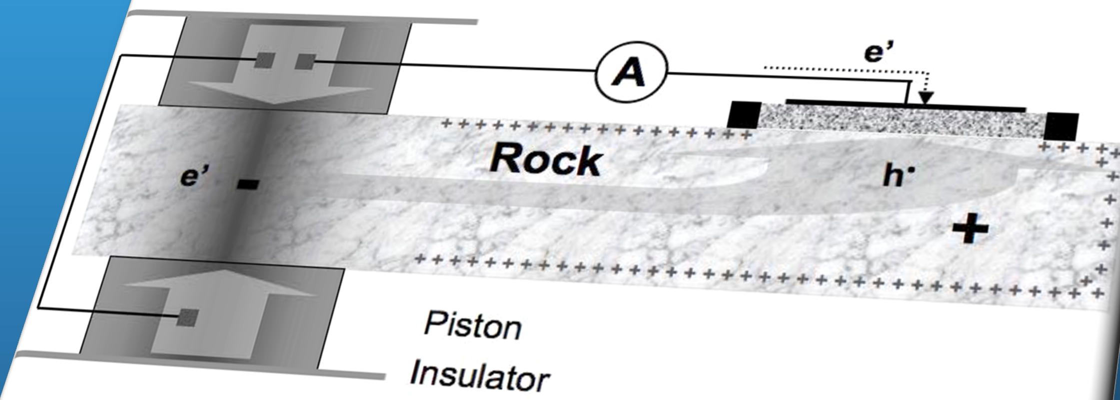
Background:



- The source of the earthquake generates acoustic and gravity waves that propagate laterally and upward, away from the source and through the ionospheric layers.

Background:



- Anomalies originate possibly from positive electric charges from stressed rocks, as demonstrated by laboratory experiments [e.g., Freund, 2013], and subsequent redistribution of ionospheric electrons [Kuo et al., 2014; Kelley et al., 2017].

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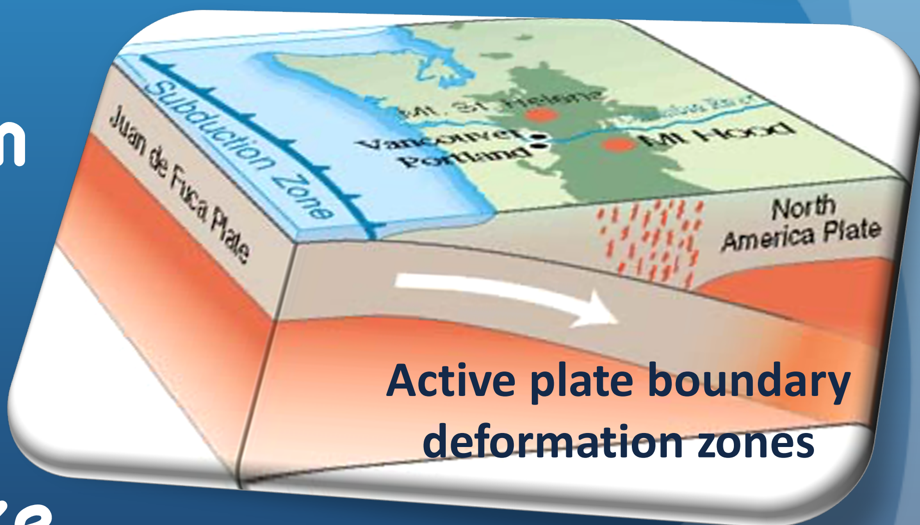
Background:

Current remote sensing technologies have become a valuable tool for detecting and measuring early warning signals from locations where stresses build up deep in the Earth's crust, presumably associated with earthquake events...



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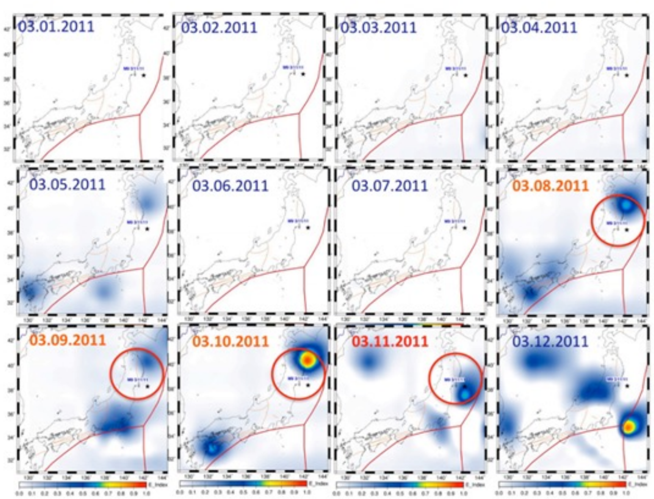
Background:

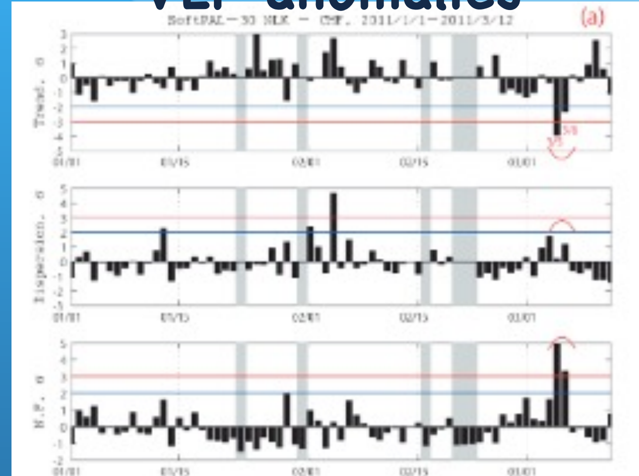
IR emissions



[*Ouzounov et al.*, 2011]

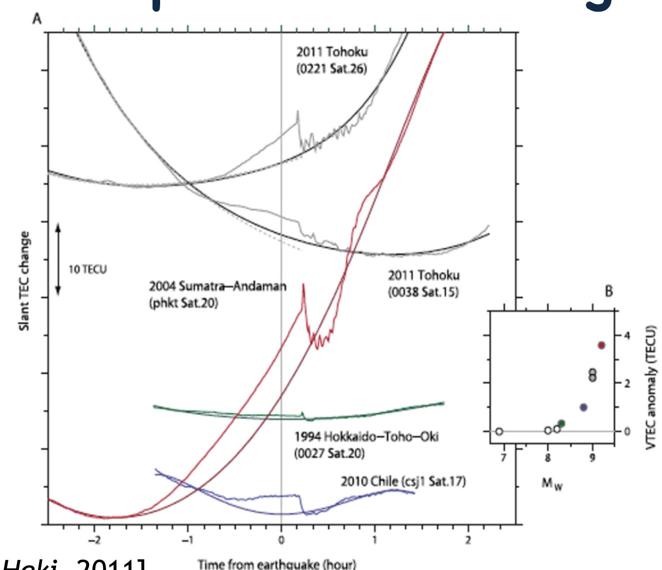
The radioactivity from radon ionizes the air. Water molecules are attracted to ions in the air, leading to condensation of water which releases heat

VLF anomalies



[*Hayakawa et al.*, 2012]

Ionospheric TEC changes

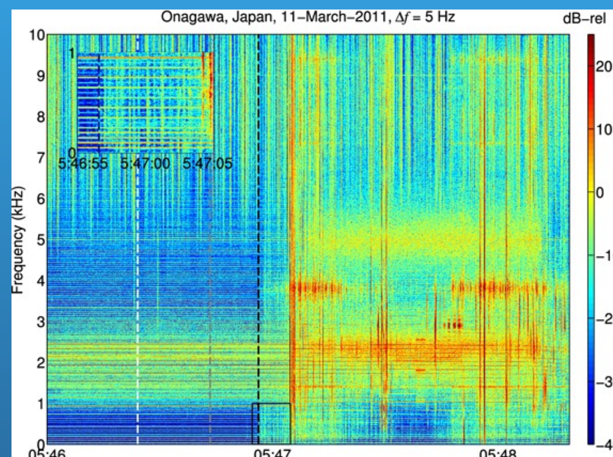


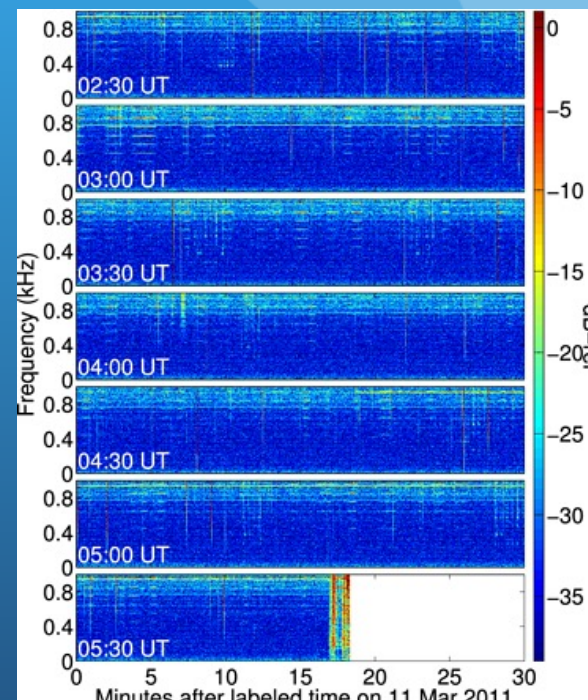
[*Heki*, 2011]

Background:

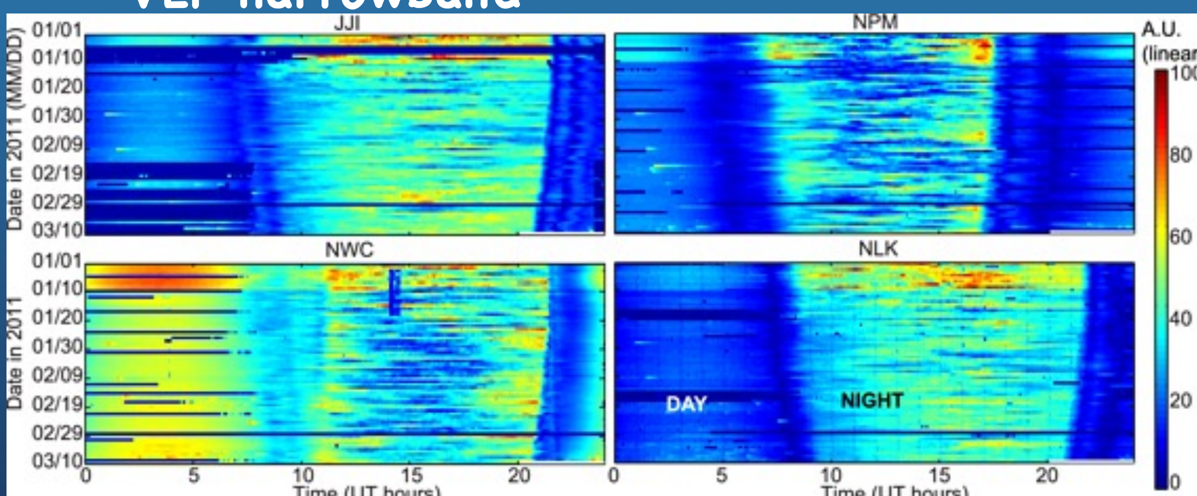
ELF/VLF broadband

[*Cohen and Marshall*, 2012]





VLF narrowband



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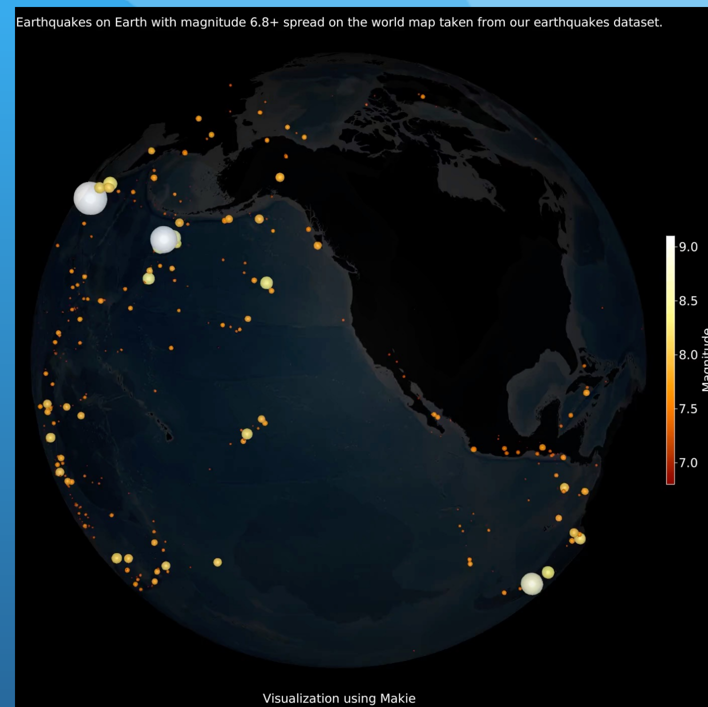
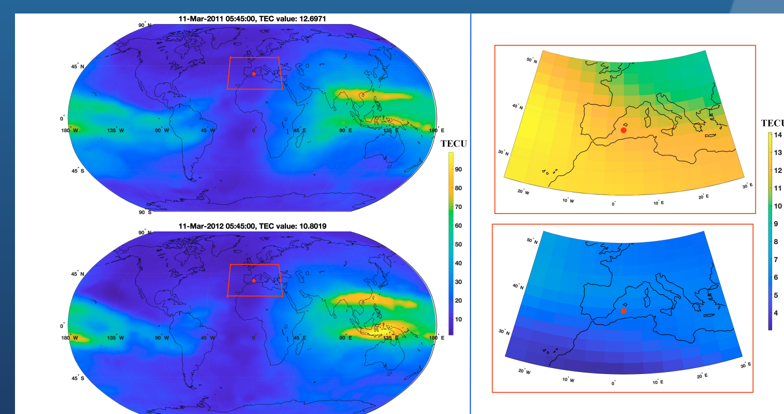
Data sources:

- Earthquakes (1998-2021 > 6 Mw). eliminating all non-related geodynamic effects (e.g., solar flares, geomagnetic storms, x-ray flux, SSN < 50) – USGS.
- TEC data for the day of the earthquake and 48 consecutive hours before. Global VTEC maps every 15 minutes with 5° x 2.5° spatial resolution – IGS.
- Solar Flares and geomagnetic storms Dataset - NOAA SWPC.





Methodology:

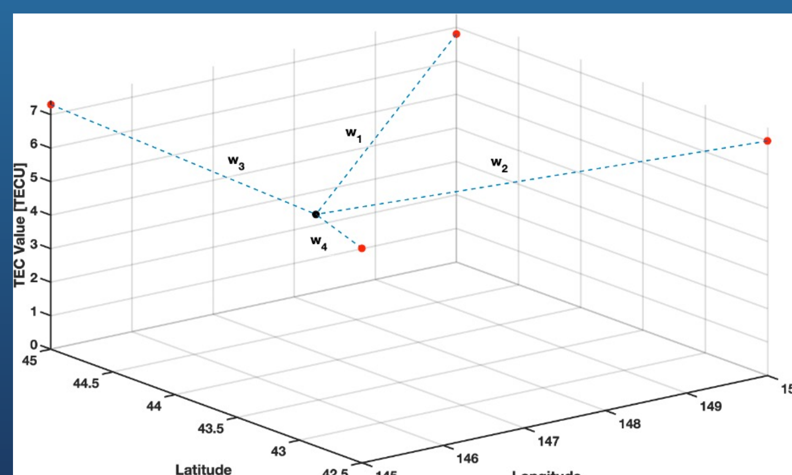
- Tec data rejection – excluding all days where there were solar disturbances and strong solar flares activity, due to the influence of Extreme UV and X-ray radiation.

- TEC data pre-processing

  – Epicenter TEC value evaluation using the weighted average value of the closest available points in the map

$$Value = \frac{\sum_{i=1}^{size(V)} (\mathrm{W_i} \cdot V_i)}{\sum_{w \in W} w}$$

W_i is the weight of the i'th neighbor which is defined as its inverse distance from the epicenter, and V_i is its value.



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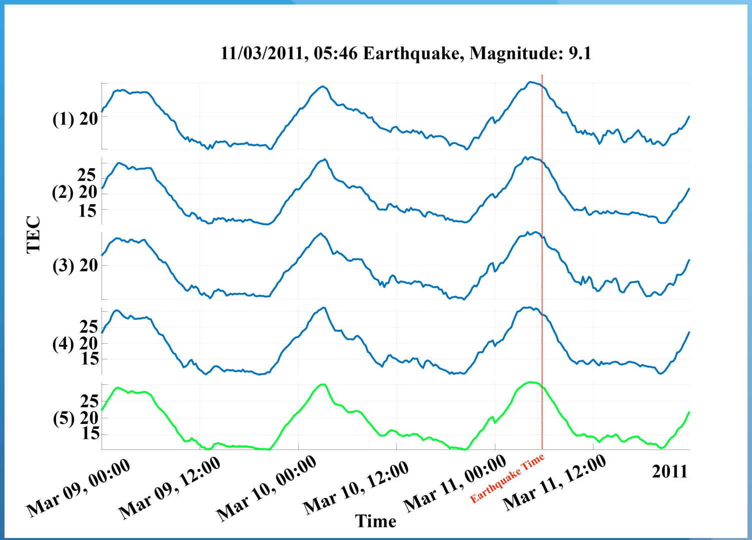
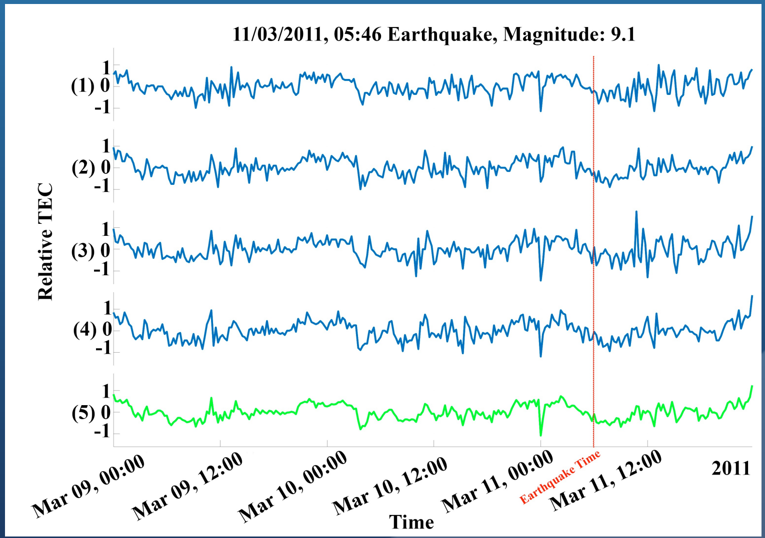
Methodology:

- TEC time series generation – 48h before each recorded main shock.

- TEC time series detrending – filtering solar activity diurnal trend, by subtracting a smoothed moving average time window size, equal to 1h of data from our original timeseries data.





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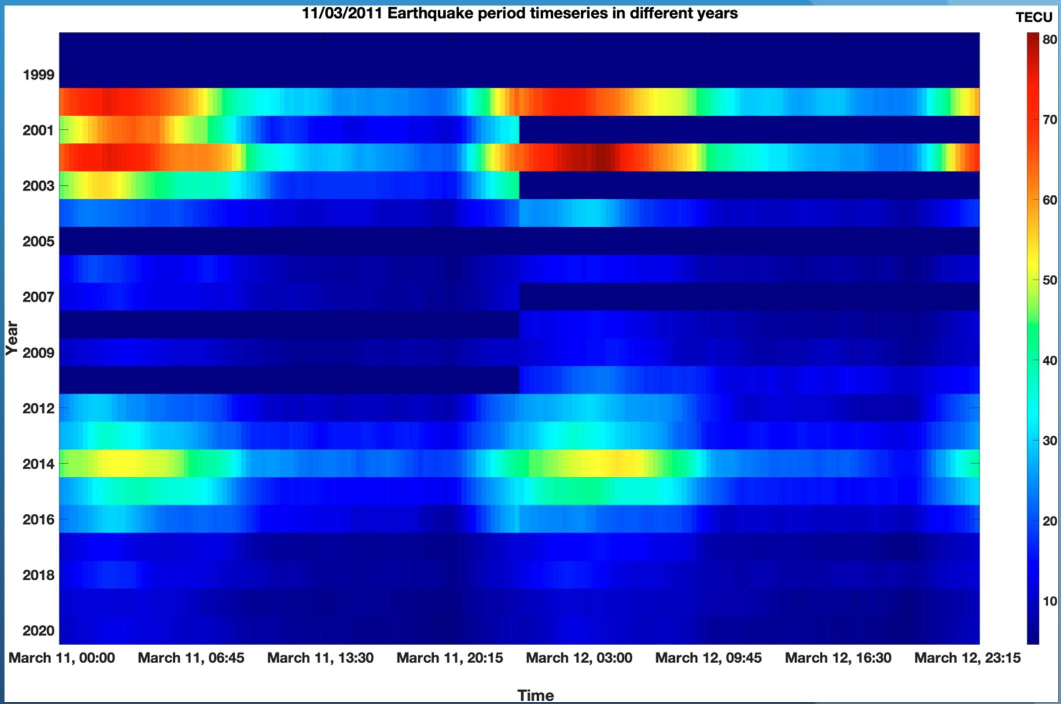
Methodology:

- Ionospheric Quiet days – mean and STD TEC timeseries estimations.

quiet day corresponding to an earthquake event – the same day and time at a different year where there were no earthquake or solar disturbance (solar storm or high sunspots number) events



15 candidate days from which we randomly pick one for each training set

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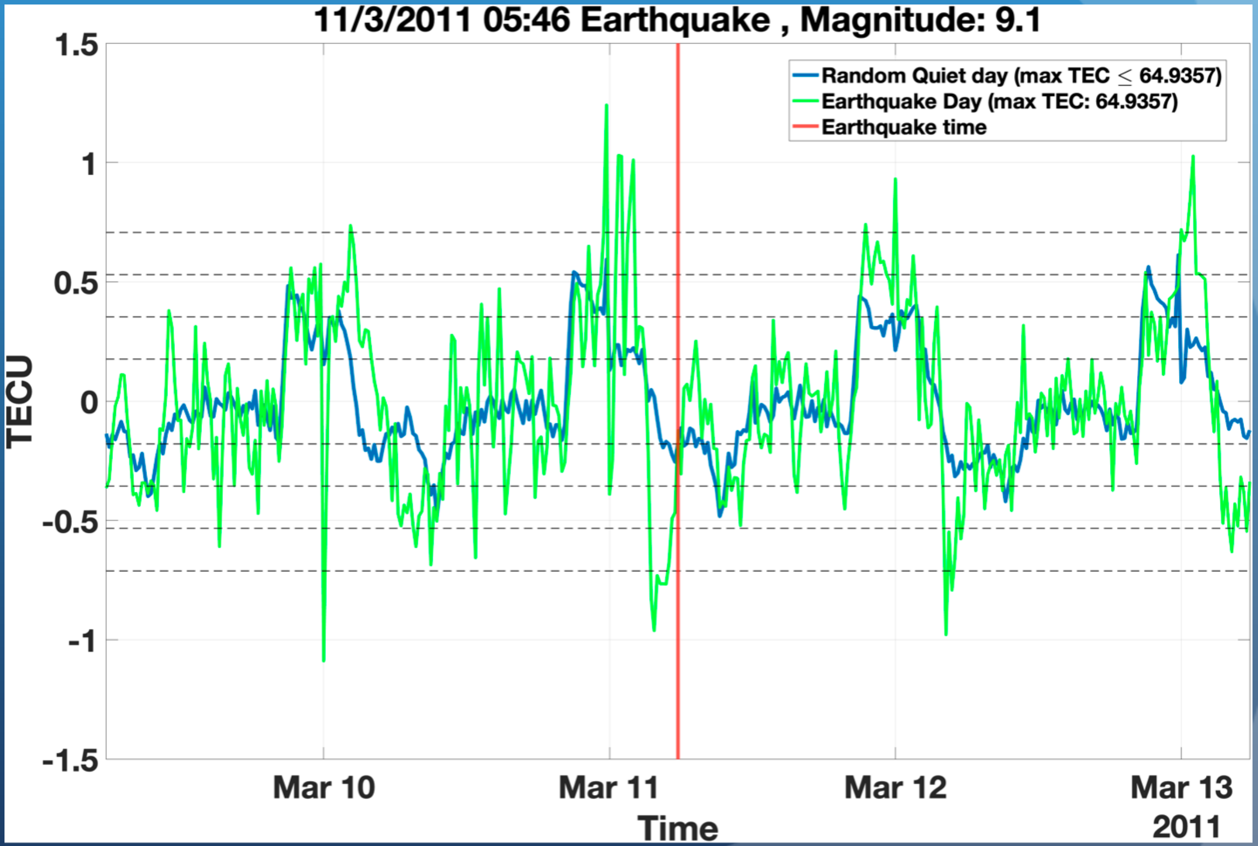
Methodology:

- Ionospheric Quiet days – mean and STD TEC timeseries estimations.

An example of a randomly picked quiet day from the quiet days corresponding to the 9.1 Tohoku earthquake occurred in 11/03/2011. Within a two days' time window before the earthquake event, the ionospheric TEC values exceeds 4 times the STD of the randomly chosen quiet day

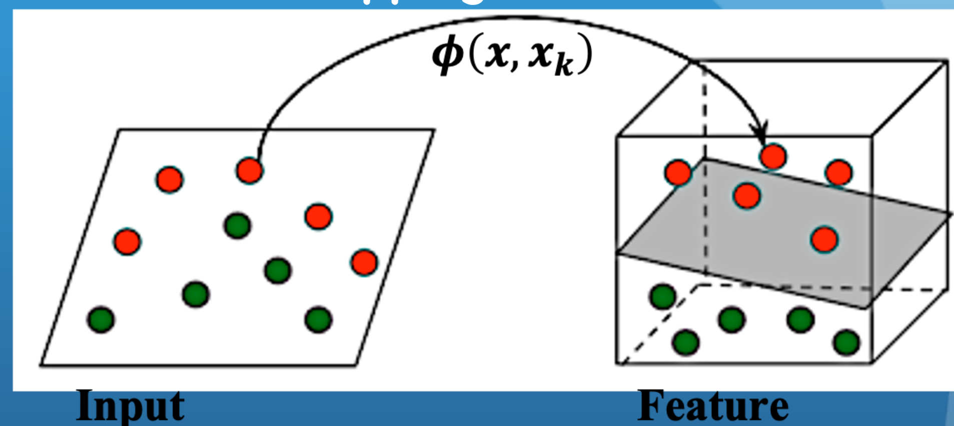


Methodology:

Support Vector Machines (SVM)

An algorithm that maps the feature inputs space into a higher dimensional feature space that can be separated more easily by linear models.

Kernel function = spatial mapping function



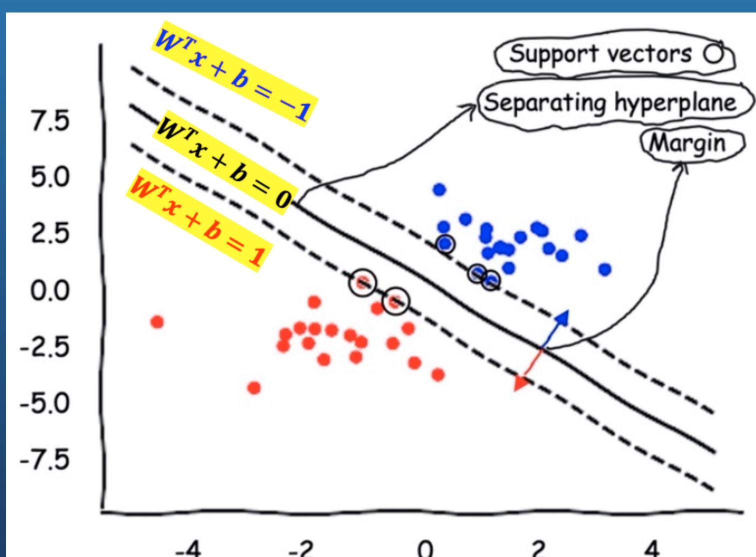
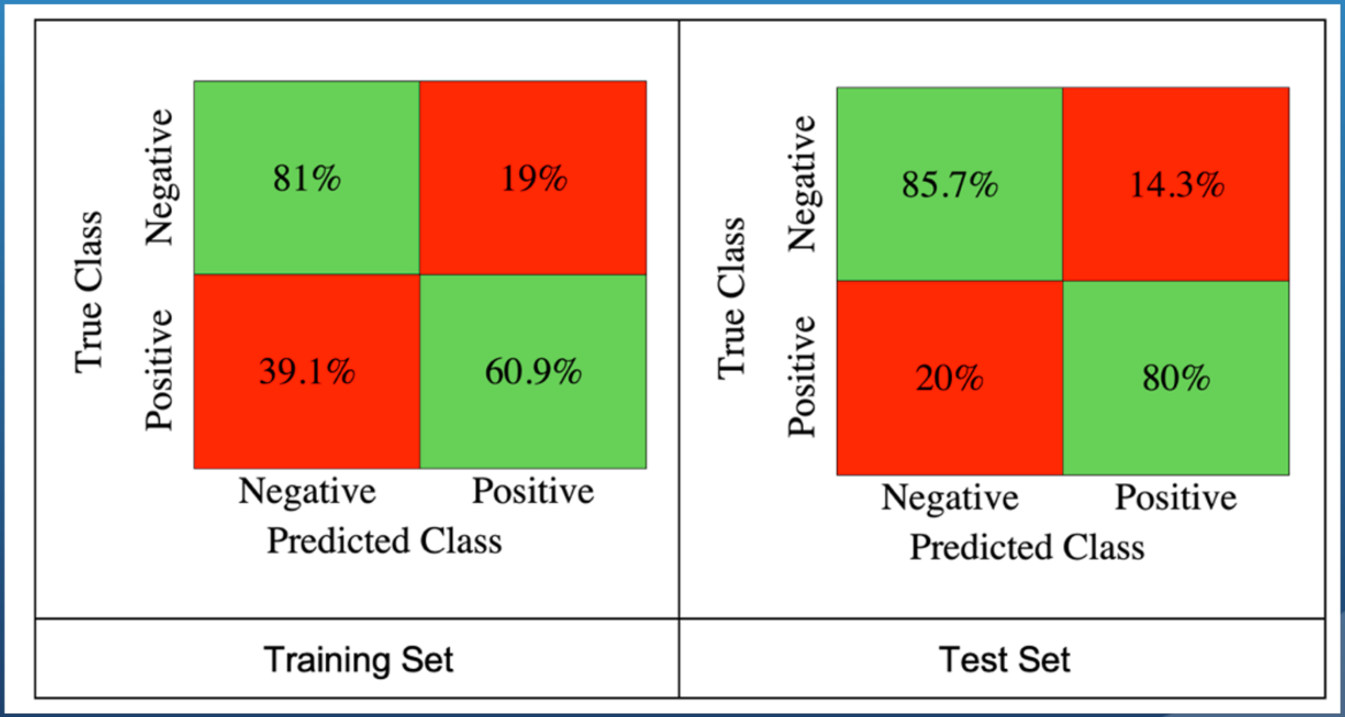


Illustration for the SVM definitions, with blue dots indicating data points of type 1, and red dots indicating data points of type -1. The blue and red arrows indicate the margin of the hyper-plane, and the points surrounded by black circles are the support vectors

Experimental Results:

Our model performance results using known skill score metrics composed of different combinations between true positive (TP), false negative (FN), true negative (TN) and false positive (FP) ratios



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Experimental Results:

Skill score indices:

$$Precision = \frac{TP}{TP + FP}$$

$$Recall = \frac{TP}{TP + FN}$$

$$HSS = \frac{2 \cdot [(TP \times TN) - (FN \times FP)]}{(TP + FN) \cdot (FN + TN) + (TP + FN) \cdot (FP + TN)}$$

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} = \frac{TP + TN}{P + N}$$

$$TSS = \frac{TP}{TP + FN} - \frac{FP}{FP + TN}$$

	Precision	Recall	HSS	Accuracy	TSS
Training Set (n=84)	0.76	0.609	0.419	0.7095	0.419
Test Set (n=22)	0.85	0.8	0.657	0.8285	0.657

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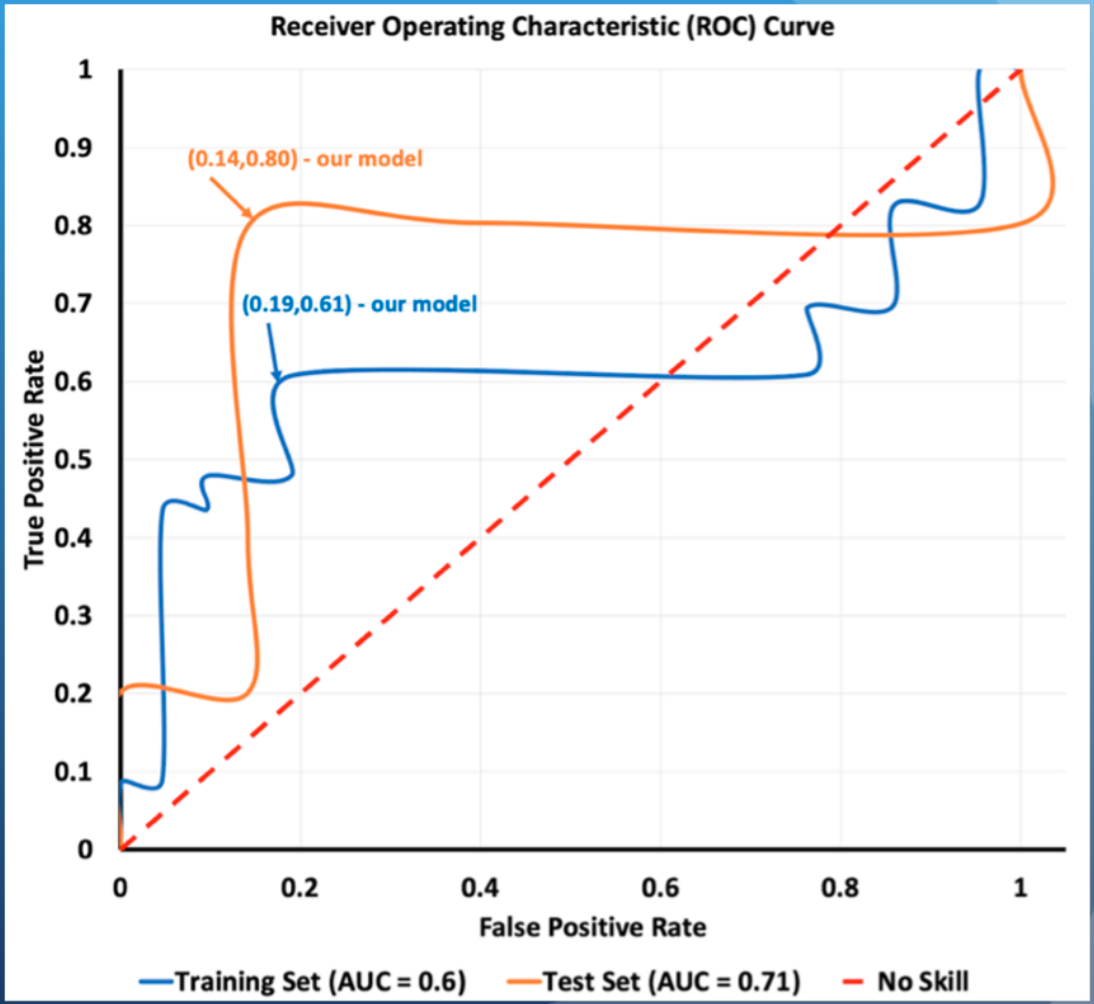
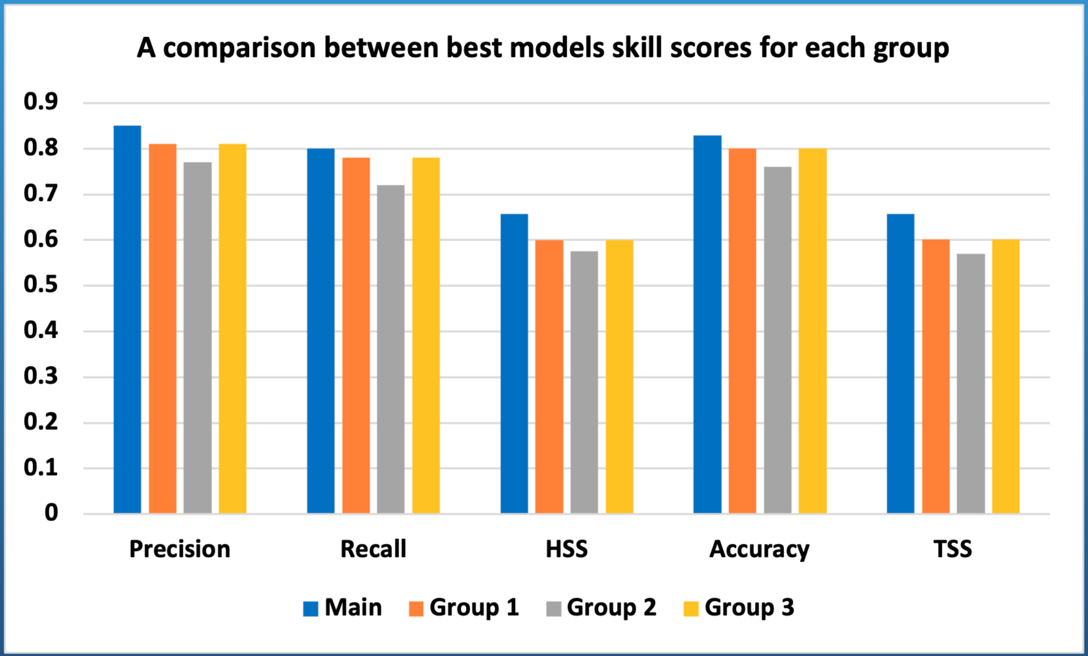
Experimental Results:

The ROC analysis provides tools to select possibly the optimal models and discard suboptimal ones independently from the cost context or the class distribution. ROC curve for best model is obtained during the hyperparameters optimization process.



Experimental Results:



Group 1: For each earthquake, 25 quiet days have been added.

Group 2: The earthquakes that are taken into account are those which occurred inland (19 event).

Group 3: The earthquakes that are taken into account are those which occurred in the ocean (87 event)

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Conclusions:

Whether or not a TEC anomalies can be a precursor for an earthquake?

- Using SVM applied with ionospheric TEC data, derived from worldwide GPS geodetic network receiver, in order to evaluate the possibility of predicting large (≥ 6Mw) earthquakes event.

- Our experimental results show that using TEC as an earthquake precursor predictor can be potentially useful for large earthquakes, with an accuracy of 82%, as well as 0.657 TSS and HSS skill scores.

- This shows that potentially, the TEC signal can be used as a precursor predictor to earthquakes within 48 hours before the earthquake time

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Questions?